Predictors of shunt during carotid endarterectomy with routine electroencephalography monitoring

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Background: **The routine use of intraoperative electroencephalography (EEG) monitoring with selective shunt placement during carotid endarterectomy (CEA) has been shown to be safe and effective. We attempt to identify the anatomic and clinical factors associated with significant EEG changes requiring shunt placement during CEA.**

Methods: **Between January 2005 and June 2007, 242 CEAs were performed with selective shunt placement for significant EEG changes. Risk factors assessed include severity of both ipsilateral and contralateral disease, presence of ipsilateral preoperative symptoms, hypertension, coronary artery disease, diabetes, age, gender, and preemptive intraoperative blood pressure manipulation to ≥20% above baseline before cross-clamping. Data were analyzed with the χ^2 test ($P < .05$ was significant).**

Results: **CEA was performed for asymptomatic disease in 177 of 242 patients (73.1%). The perioperative stroke rate was 0.8% (2 of 242), and the overall morbidity rate was 4.5%. No patients died. Significant EEG changes requiring shunt occurred in 35 patients (14.46%). Factors associated with carotid shunt placement were moderate ipsilateral carotid artery stenosis (50% to 79%) compared with severe (≥80%) disease (30.6% vs 11.7%, $P = .003$) and degree of contralateral carotid stenosis (0% to 49%, 10.8%; 50% to 79%, 10.9%; 80% to 99%, 23.2%; occlusion, 50%; $P = .0003$). Presence of symptoms, gender, age, hypertension, diabetes, or coronary artery disease, and preemptive intraoperative manipulation of blood pressure were not significant predictors of shunt placement.**

Conclusion: **CEA performed with routine EEG monitoring and selective shunt placement is associated with a low risk of perioperative stroke. Identified predictors of significant EEG changes were anatomic factors including degree of contralateral carotid artery disease and moderate ipsilateral carotid artery stenosis (50% to 79%). Although contralateral carotid occlusion has been accepted as indication for shunt placement in the absence of cerebral monitoring, this study suggests that high-grade contralateral disease and moderate ipsilateral carotid stenosis are associated with cerebral ischemia resulting in EEG changes and should prompt consideration for nonselective shunting. (J Vasc Surg 2009;49: 1374-8.)**

Carotid endarterectomy (CEA) has been shown to be the most effective treatment in preventing cerebrovascular events in selected patients.[1-4] The practice of cerebral monitoring and the use of carotid shunt placement remains variable. More recently, studies have suggested that monitoring and selective shunt use during CEA decreases the risk of perioperative stroke and can be superior to routine shunt placement.[5,6] Electroencephalography (EEG) is a sensitive indicator of cerebral ischemia,[7-9] and CEA performed with routine EEG monitoring and selective shunt placement is safe and effective.[10-13]

The aim of this study was to examine the clinical and anatomic factors associated with significant EEG changes that required shunt placement in CEA performed with routine EEG monitoring.

METHODS

Records of consecutive patients who underwent CEA between January 2005 and June 2007 at our hospital by the Division of Vascular Surgery were reviewed. The protocol of this study was reviewed and approved by the Institutional Review Board. Data relating to clinical presentation, patient comorbidities, patient demographics, operative details, hospital stay, and outpatient follow-up were collected retrospectively from the hospital record, anesthesia record, office record, radiology record, vascular laboratory record, and EEG record. Duplex ultrasound scanning was the standard preoperative imaging study. The ultrasound criteria for internal carotid artery (ICA) stenosis have been standardized as published by University of Washington.[14]

Computed tomography angiography (CTA), magnetic resonance angiography (MRA), and carotid angiography were used to supplement the duplex scanning selectively at the discretion of attending surgeons. The information obtained was used to better define the primary pathology of the carotid plaque, but information about the collateral circulation did not influence the decision for intraoperative shunt placement.

Patients included in this study underwent primary CEA performed with routine EEG monitoring and selective shunt placement, which is the standard practice pattern within the Division of Vascular Surgery. The study excluded patients who had undergone secondary CEA for recurrent stenosis, repair of carotid artery aneurysm, excision of carotid tumor, combined CEA and coronary artery bypass grafting, ligation of a non-reconstructable or oc-

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Competition of interest: none.

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0741-5214/$36.00

doi:10.1016/j.jvs.2009.02.206

cluded ICA, CEA performed without EEG monitoring during the study period due to unavailability of EEG, and CEA performed with primary shunt placement.

The EEG recording was obtained from a digital EEG system that used 12 separate electrodes. A preoperative EEG was performed as baseline. The EEG recording was started before anesthesia induction and continued throughout the procedure. Close communication was maintained between the anesthesiologist, the EEG technologist, and the operating team. The EEG technologist performed visual interpretation of digital EEG tracing, and any 10% decrease in EEG amplitude or frequency was considered significant. Persistence or progression of these EEG changes resulted in shunt placement. Shunt placement resulted in reversal of all EEG changes seen during carotid cross-clamping. The Argyle shunt (Covidien, Mass) or the Javid shunt (Tempe, Ariz) was used for all patients with significant intraoperative EEG changes.

The primary outcome measured was EEG change requiring shunt placement. Anatomic and clinical factors associated with shunt placement were evaluated. The risk factors investigated included severity of both ipsilateral and contralateral disease, presence of ipsilateral preoperative symptoms, hypertension, coronary artery disease, diabetes, age, gender, and preemptive intraoperative blood pressure (BP) manipulation to ≥20% above baseline before carotid clamping. Intraoperative BP manipulations before carotid cross-clamping were selective at the discretion of attending surgeons. Elevation of intraoperative BP to ≥20% above baseline BP measure in preanesthesia care area was performed with hemodynamic agents at the discretion of attending surgeon and anesthesiologist intraoperatively.

The ability of patient characteristics to predict outcomes was assessed using the χ^2 test and logistic regression. A value of $P < .05$ was considered statistically significant.

RESULTS

Between January 2005 and June 2007, 282 consecutive CEAs were performed. Our study group consisted of 242 primary CEAs performed in 234 patients (58% men) who were a mean age of 72 years. Eight patients underwent bilateral staged CEA for bilateral carotid stenosis. Demographics and comorbidities of the patients are listed in Table I. CEA was performed for asymptomatic carotid artery stenosis in 177 patients (73.1%), and 35 (14.46%) required shut placement for significant EEG changes. The most frequent changes observed with cross-clamping were a decrease of EEG amplitude or EEG slowing. The most common EEG changes were ipsilateral changes in 29 of 35 (82.9%), but bilateral (8.6%) and contralateral (8.6%) changes were also seen.

Surgical outcome data are provided in Table II. The perioperative stroke and neurologic event rate was 0.83% (2 of 242). One event occurred in the asymptomatic group (0.56% stroke rate) and the other in symptomatic group (1.54% stroke rate). The patient in the asymptomatic group had a patent contralateral ICA and underwent an uneventful left CEA but presented 5 days after surgery with ipsilateral stroke. The other stroke occurred in the symptomatic group. This patient had confusion 4 hours after emergence from general anesthesia and was found to have an ipsilateral frontal stroke. Neither neurologic event was associated with intraoperative EEG changes and therefore did not require shunt placement. There was no operative mortality. The overall morbidity rate was 4.5%, including six (2.48%) with cardiac events (cardiac arrhythmia and myocardial infarct) and three (1.24%) returned to operating room due to bleeding or hematoma. Postoperatively, one patient had injury to the ipsilateral mandibular branch of the facial nerve.

Table I. Patient demographic and comorbidities

Variable	*No. (%) or mean (range)*
Total patients	242 (100)
Age, years	71.59 (48-86)
Male	140 (57.9)
Hypertension	202 (84.2)
Diabetes mellitus	61 (25.2)
History of cigarette smoking	166 (68.6)
History of CHD/CHF	118 (48.8)
Symptomatic	67 (27.7)
Stroke	23 (9.5)
Transient ischemic attack	44 (18.2)

CAD, Coronary heart disease; *CHF,* congestive heart failure.

Table II. Outcome of surgery

Event	*No. (%)*
Ipsilateral neurologic event	2 (0.83)
Cardiac event (MI, arrhythmia)	6 (2.48)
Return to OR for bleeding	3 (1.24)
Total morbidity	10 (4.55)
Perioperative death	0

MI, Myocardial infarct; *OR,* operating room.

Clinical factors, including the presence of symptoms (stroke and transient ischemia attack), male gender, age ≥80 years, hypertension, diabetes, coronary artery disease, and history of tobacco use were not significant predictors for shunt placement using logistic regression analysis (Table III). Preemptive intraoperative manipulation of BP to ≥20% baseline before carotid cross-clamping did not significantly reduce the need for shunt (odds ratio [OR], 1.40; 95% confidence interval [CI], 0.68-2.91; $P = .36$; Table IV).

Contralateral ICA disease was a significant predictor of EEG changes, with a shunt rate of 10.8% for 0% to 49% occlusion, 10.9% for 50% to 79%, 23.2% for 80% to 99%, and 50% for total occlusion ($P = .0005$). The Mantel-Haenszel χ^2 test indicated EEG changes were more likely to occur with increasing ipsilateral ICA stenosis ($P = .0003$; Fig). When ipsilateral disease was compared, moderate (50% to 79%) ipsilateral ICA stenosis was more likely to be associated with EEG changes necessitating shunt placement than severe (80% to 99%) ipsilateral ICA stenosis (OR, 3.31; 95% CI, 1.44-7.60; $P = .003$; Table V).

Table III. Univariate analysis of clinical factors associated with shunt placement during carotid endarterectomy

Factor	*Shunt rate, %*	*OR (95% CI)*	P
Symptomatic (stroke, TIA) vs asymptomatic	17.91 vs 13.61	1.39 (0.65-2.97)	.40
Stroke vs no stroke (asymptomatic, TIA)	26.09 vs 13.62	2.23 (0.82-6.15	.11
Age ≥80 vs <80 years	11.11 vs 15.59	0.68 (0.27-1.73)	.41
Male vs female	13.57 vs 16.00	0.82 (0.40-1.70)	.60
Hypertension	15.84 vs 7.89	2.20 (0.64-7.57)	.20
Diabetes mellitus	9.84 vs 16.20	0.56 (0.22-1.43)	.22
History of cigarette smoking	12.05 vs 18.64	0.60 (0.27-1.34)	.21
History of CHD/CHF	13.56 vs 15.83	0.83 (0.41-1.71)	.62

CHD, Coronary heart disease; *CHF,* congestive heart failure; *CI,* confidence interval; *OR,* odds ratio; *TIA,* transient ischemic attack.

Table IV. Univariate analysis of routine intraoperative blood pressure manipulation associated with shunt placement during carotid endarterectomy

BP elevation before clamping	*Shunt rate, %*	*OR (95% CI)*	P
Routine ≥20% baseline vs <20%	15.07% vs 6.06%	1.40 (0.68-2.91)	.36

BP, Blood pressure; *CI,* confidence interval; *OR,* odds ratio.

Multiple logistic regressions were performed to evaluate the independence of categoric anatomic factors as predictors of shunt placement. No two-way interaction was identified when the degree of contralateral stenosis and moderate ipsilateral stenosis, which univariate analysis found was a significant predictor of EEG changes necessitating shunt placement, underwent multivariate analysis.

DISCUSSION

Various multicenter trials have shown CEA to be beneficial in symptomatic[1,2] and asymptomatic carotid artery stenosis in selected patients.[3,4] The method of intraoperative cerebral monitoring remains variable. Recent studies have suggested that selective shunting with routine monitoring, including EEG, carotid stump pressure measurement, and awake patients with local anesthesia, are associated with a low perioperative stroke rate and morbidity.[5,6] Most perioperative strokes are related to thromboembolic phenomena during carotid surgery.[15-18] CEA performed without a carotid shunt eliminates the potential risk of plaque dislodgement or distal vessel injury caused during shunt placement and may allow better visualization of the endarterectomy end point. Intraoperative EEG monitoring has been an established method to detect cerebral ischemia during carotid surgery,[7-9] and various studies have shown CEA performed with routine EEG monitoring and selective shunt placement is safe and associated with a relatively low rate of perioperative stroke.[10,11,19] In this study, we attempted to identify the clinical and anatomic predictors associated with significant EEG changes during CEA performed with routine EEG monitoring.

Perioperative morbidity and mortality in our series was comparable with other series of CEA.[1-4] Our overall shunt rate of 14.46% was similar to other studies that used routine intraoperative EEG monitoring to direct selective shunt placement.[11,20] In the two patients who presented with strokes in our series, the strokes occurred ≥4 hours after emergence from general anesthesia. Neither neurologic event was associated with EEG changes; therefore, no shunt was place intraoperatively. Intraoperative stroke was not observed with routine EEG monitoring and selective shunt placement in our series. Schneider et al[11] and Ballotta et al[21] had made similar observation in their series of CEAs.

Previous studies have shown that contralateral occlusion was associated with significant EEG changes during CEA.[11] Our study demonstrated that in addition to contralateral occlusion, patients with higher degrees of contralateral ICA disease are significantly more likely to exhibit EEG changes consistent with cerebral ischemia than those with lesser degree of contralateral ICA disease. Despite that, most patients with contralateral stenosis tolerated carotid cross-clamping without EEG changes. The eight patients who had bilateral staged CEAs in our series did not have EEG changes during their first operation despite significant contralateral disease, reflecting the variability of cerebral perfusion. We have also found that patients with moderate ipsilateral ICA stenosis (50% to 79%) were paradoxically more likely to be associated with EEG changes during clamping compared with those with severe ipsilateral ICA stenosis (80% to 99%). This may reflect the greater relative loss of ipsilateral flow as a result of clamp placement in the moderate stenosis group. Both anatomic factors were predictors for shunt during CEA in this study.

We compared the BP in the preanesthesia area and intraoperative BP before carotid cross-clamping to identify patients with elevation of BP to >20% above baseline. This was performed selectively at the discretion of the attending surgeons. Although reversal of EEG changes with intraoperative manipulation of BP has been described[22,23] and we have frequently observed the return of the EEG pattern to baseline with simple elevation of BP, the practice of preemptive intraoperative manipulation of BP before carotid clamping did not reduce the incidence of significant EEG changes in our series.

Intraoperative evaluation of EEG is subjective and technician-dependent. A single experienced EEG technician was available for all our procedures, which limited the variability of EEG interpretation as an additional source of error. Some articles have suggested patients with apparent EEG changes during clamping would not have apparent perioperative strokes,[7,9] but our series showed that intraoperative EEG monitoring appeared to be an excellent

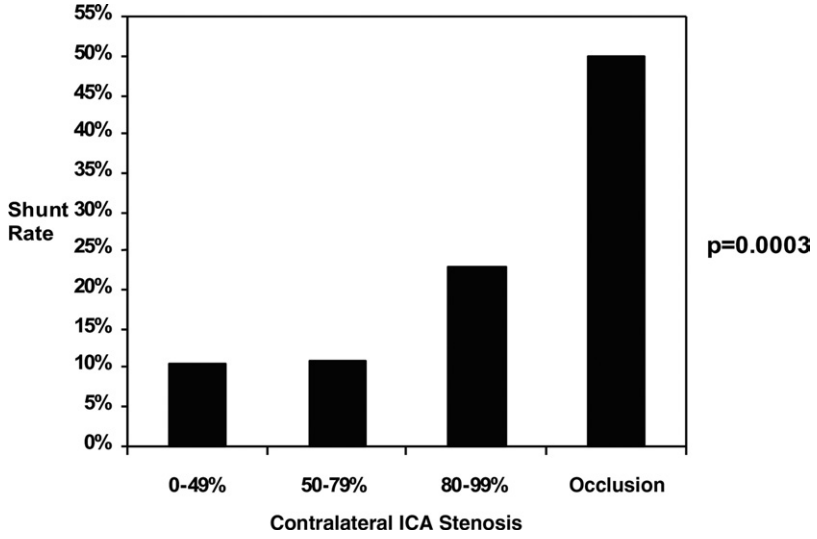

Fig. Shunt rate percentage with degree of contralateral internal carotid artery (*ICA*) stenosis.

Table V. Univariate analysis of anatomic factors associated with shunt placement during carotid endarterectomy

Factor	*Shunt rate, %*	*OR (95% CI)*	P
Contralateral occlusion			
Yes vs no	50 vs 14.9	7.30 (2.36-22.4)	.0001
Ipsilateral ICA occlusion			
50%-79% vs 80%-99%	30.56 vs 11.73	3.31 (1.44-7.60)	.003

CI, Confidence interval; *ICA,* internal carotid artery; *OR,* odds ratio.

method for routine monitoring and to direct selective shunt placement.

CONCLUSIONS

CEA performed with routine EEG monitoring and selective shunt placement is safe and provides optimal patient outcomes. The incidence of significant EEG changes requiring shunt placement increases with the degree of contralateral ICA stenosis. Ipsilateral moderate (50% to 79%) ICA stenosis is also more likely to be associated with such significant EEG changes and probably reflects the greater relative loss of ipsilateral flow during clamping. Clinical factors, including preoperative symptoms and routine intraoperative manipulation of BP before clamping, were not predictive of EEG changes. Although contralateral occlusion has been an indication for nonselective shunt placement in the absence of cerebral monitoring, our data suggest that moderate (50% to 79%) ipsilateral stenosis and severe (80% to 99%) contralateral stenosis are also associated with a high incidence of cross-clamp–associated EEG changes suggestive of cerebral ischemia and should prompt consideration for nonselective shunt placement.

AUTHOR CONTRIBUTIONS

Conception and design: TT, MG, EM, WC, JS
Analysis and interpretation: TT, EM, WC, JS, JM
Data collection: TT, MG
Writing the article: TT
Critical revision of the article: TT, EM, JS
Final approval of the article: TT, EM, JS, JM
Statistical analysis: TT, JM
Obtained funding: EM
Overall responsibility: TT, EM, JS

REFERENCES

1. North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N Engl J Med 1991;325:445-53.
2. Barnett HJM, Taylor DW, Eliasziw M, Fox AJ, Ferguson GG, Haynes RB, et al. Benefit of carotid endarterectomy in patients with symptomatic moderate to severe stenosis. N Engl J Med 1998;339:1415-25.
3. Executive Committee for the Asymptomatic Carotid Atherosclerosis Study. Endarterectomy for asymptomatic carotid artery stenosis. JAMA 1995;273:1421-8.
4. Halliday A, Mansfield A, Marro J, Petro C, Petro R, Potter J, et al; MRC Asymptomatic Carotid Surgery Trial (ACST) Collaborative Group. Prevention of disabling and fatal strokes by successful carotid endarterectomy in patients without recent neurological symptoms: randomized controlled trial. Lancet 2004;363:1491-502.
5. Woodworth GF, McGirt MJ, Than KD, Huang J, Perler BA, Tamargo RJ. Selective versus routine intraoperative shunting during carotid endarterectomy: a multivariate outcome analysis. Neurosurgery 2007;61:1170-7.
6. Blackshear WM, DiCarlo V, Seifert KB, Connar RG. Advantages of continuous electroencephaloghic monitoring during carotid artery surgery. J Cardiovasc Surg 1986;27:146-53.
7. Faught E. Loss of high frequency EEG activities as a sensitive indicator of cerebral ischemia. Electroencephalogr Clin Neurophysiol 1984;58:119p.
8. McGrail KM. Intraoperative use of electroencephalography as an assessment of cerebral blood flow. Neurosurg Clin North Am 1996;7:685-92.

9. Harada RN, Comerota AJ, Good GM, Hashemi HA, Hulihan JP. Stump pressure, electroencephalographic changes, and the contralateral carotid artery: another look at selective shunting. Am J Surg 1995;170: 148-53.
10. Salvian AJ, Taylor DC, Hsing YN, Hildebrand HD, Litherland HK, Humer MP, et al. Selective shunting with EEG monitoring is safer than routine shunting for carotid endarterectomy. Cardiovasc Surg 1997;5: 481-5.
11. Schneider JR, Droste JS, Schindler N, Golan JF, Bernstein LP, Rosenberg RS. Carotid endarterectomy with routine electroencephalography and selective shunting: Influence of contralateral internal carotid artery occlusion and utility in prevention of perioperative strokes. J Vasc Surg 2002;35:1114-22.
12. Cho I, Smullens SN, Streletz LJ, Fariello RG. The value of intraoperative EEG monitoring during carotid endarterectomy. Ann Neurol 1986;20:508-12.
13. Plestis KA, Loubser P, Mizrachi EM, Kantis G, Jiang ZD, Howell JF. Continuous electroencephalography monitoring and selective shunting reduces neurological morbidity rates in carotid endarterectomy. J Vasc Surg 1997;25:620-8.
14. Taylor DC, Strandness DE. Carotid artery duplex scanning. J Clin Ultrasound 1987;15:635-44.
15. Jacobowitz GR, Rockman CB, Lamparello PJ, Adelman MA, Schanzer A, Woo D, et al. Causes of perioperative stroke after carotid endarterectomy: special considerations in symptomatic patients. Ann Vasc Surg 2001;15:19-24.
16. Smith JL, Evans DH, Fan L, Gaunt ME, London NJ, Bell PR, et al. Interpretation of embolic phenomenon during carotid endarterectomy. Stroke 1995;26:2281-4.
17. Steed DL, Peitaman AB, Grundy BL, Webster MW. Causes of stroke in carotid endarterectomy. Stroke 1982;92:634-41.
18. de Borst GJ, Moll FL, van de Pavoordt HD, Mauser HW, Kelder JC, Acherstaf RG. Stroke from carotid endarterectomy: when and how to reduce perioperative stroke? Eur J Vasc Surg 2001;21:484-9.
19. Pinkerton JA Jr. EEG as a criterion for shunt need in carotid endarterectomy. Ann Vasc Surg 2002;16:756-61.
20. Bond R, Rerkasem K, Counsell C, Salinas R, Naylor R, Warlow CP, et al. Routine or selective carotid artery shunting for carotid endarterectomy (and different methods of monitoring in selective shunting). Cochrane Database Syst Rev 2002;2:CD000190.
21. Ballotta E, Dagiau G, Saladini M, Bottio T, Abbruzzese E, Meneghetti G, et al. Results of electroencephalographic monitoring during 369 consecutive carotid atery revascularizations. Eur Neurol 1997;37:43-7.
22. Aleksic M, Heckenkamp J, Gawenda M, Reichest V, Brunkwall J. Evaluation of changes of systemic blood pressure and shunt incidence in CEA. Eur J Vasc Endovasc Surg 2007;34:540-5.
23. Barman AA, Batiuchok W, Creedon JJ, Anban T. Carotid endarterectomy without temporary shunt: importance of pharmacological control of blood pressure. N Y State J Med 1983;83:697-8.

Submitted Dec 15, 2008; accepted Feb 12, 2009.